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γ-Ray Diagnostic for the Compact Ignition Tokamak

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ABSTRACT

We have examined the feasibility of a fusion γ-ray diagnostic for the Compact Ignition Tokamak, which is expected to produce $10^{20}$ (d,t) fusion reactions per second. Gamma rays at 16.7 MeV are produced by the t(d,γ)He$^5$ fusion reaction. A Monte-Carlo coupled neutron-photon transport code is used to model the expected γ-ray spectrum incident upon a Compton spectrometer backed by a Cerenkov detector. The results indicate that a signal of $\sim 3 \times 10^4$ cts/s and a signal-to-noise ratio of $\sim 30$ can be achieved.

INTRODUCTION

The measurement of the (d,t) fusion source function is essential for determination of burn efficiency and α energy deposition within a hot plasma. The method most often discussed for achieving this objective is based on measurement of the 14 MeV neutrons produced from the t(d,n)He$^4$ reaction. Medley and coworkers(1) pointed out, however, that energetic γ rays from the t(d,γ)He$^5$ reaction provide an attractive alternative despite the small γ branching ratio, $5 \times 10^{-5}$.2

The feasibility of the γ-ray approach is based on the premise that the 16.7 MeV γ-ray signal is measurable even in the presence of a large background of γ rays resulting from (n,γ) capture reactions in the tokamak and surrounding structure. Moran(3) and Ladish et. al.(4) suggested that a γ detection scheme based on a Cerenkov threshold detector might be adequately sensitive to
the γ signal while, at the same time, providing discrimination against the enormous γ background. In this paper we semi-quantitatively evaluate such a diagnostic for the Compact Ignition Tokamak, which will produce $10^{20}$ (d,t) fusion reactions per second.

**EXPERIMENTAL DESCRIPTION**

Figure 1 shows a simplified schematic of the plasma and γ diagnostic, and Fig. 2 an overview of the γ detector. The plasma is viewed through a B$_{10}$/LiH plug, the function of which is to partially attenuate source neutrons while transmitting source γ rays. After passage through the plug and the lead collimator, the γ rays impinge upon a Compton convertor foil (2 mm of Be). One 16.7 MeV γ ray in about 250 Compton converts within the foil, and of these approximately 1/3 are forward directed within an ~3° angle. (Compton electrons emitted at 3° (0°) possess kinetic energy of about 15 MeV (16.45 MeV).) These electrons next pass through a magnetic field of about 1500 G and are deflected 90° into a Cerenkov CO$_2$ chamber. A huge background of low-energy Compton electrons—from about 0.1 to 10 MeV—are also generated in the convertor foil. These electrons correspond to the (n,γ) background generated in the tokamak structure (especially in the inconel) and in the plug, and they are largely prevented from reaching the Cerenkov chamber by the magnetic screening field. Those electrons that enter the CO$_2$ chamber with kinetic energy in excess of 14 MeV (corresponding to a CO$_2$ pressure of 1.4 atmosphere) produce Cerenkov radiation. These photons are collected through a parabolic mirror, and focused onto a well-shielded photomultiplier.

In order to make this design more quantitative, the signal and background γ fluxes have been evaluated using the MCNP (Monte Carlo coupled neutron photon transport code). The materials and dimensions used as input to MCNP are approximately those depicted in Fig. 1. Figure 3 shows the resultant γ spectrum incident upon the converter foil. In addition, the total neutron flux at the foil is about 300 times the γ signal flux. Because of the low neutron sensitivity of the Cerenkov chamber, it is felt that the neutrons will contribute negligibly to the noise level.

An estimate of the signal-to-noise ratio is obtained by using the overall sensitivity curve of Brolley and Ladish et al. Multiplying together the γ spectrum (Fig. 3), the Compton interaction
cross section(8), and the Brolley/Ladish sensitivity curve, we obtain the curves shown in Fig. 4. The integral under the solid (dotted) curve gives the signal (noise), resulting in $S/N = 30$. It is important to note that without the screening magnet $S/N \sim 2$. Thus the magnet is essential to reduce the noise.

To estimate the signal, the following quantities are needed:

- $F_v$, fractional plasma volume viewed by the detector
- $F_\Omega$, fractional solid angle of the detector
- $T$, $\gamma$ transmission through plug and inconel
- $C$, Compton conversion factor (including forward scattering $\leq 3^\circ$)
- $M$, electron transmission through the magnet into the Cerenkov chamber
- $D$, detection efficiency in the Cerenkov chamber
- $BR$, $\gamma$ branching ratio
- $\Sigma$, fusion neutron rate

Signal ($S$): $S = (F_v)(F_\Omega)(T)(C)(M)(D)(BR)(\Sigma)$

CONCLUSIONS

In conclusion we find that a fusion $\gamma$-ray diagnostic for CIT is an attractive possibility. For a Cerenkov type detector with screening magnet, the signal-to-noise ratio and signal are of the order $\sim 30$ and $\sim 3 \times 10^4$ counts/s, respectively.

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Fig. 1 Schematic of the CIT plasma and γ-ray diagnostic.
Fig. 2 Schematic of the Detector. A small fraction of the 16.7 Mev γ rays Compton convert into forward directed electrons. These high energy electrons are bent via the magnetic field into the Cerenkov chamber. Electrons with energies greater than about 14 MeV Cerenkov radiate for a CO2 gas pressure of 1.4 Atm.
ENERGY (MeV)

Fig. 3 MCNP $\gamma$ spectra for the signal (solid line, cross hatched) and the background (dotted line). (Vertical units are relative.)
Fig. 4 The overall detection response curves for signal (solid line, cross hatched) and background (dashed line) $\gamma$ rays. The integral of the solid (dashed) curve corresponds to the signal (noise). (Vertical units are relative.)